222
```
#Initialisation
import matplotlib.pyplot as plt
import numpy as np
from scipy.integrate import simps
from scipy import signal as sg
from scipy.interpolate import RectBivariateSpline as ReBiSpline
from numpy import ma
from matplotlib import colors, ticker, cm
from random import choice
import scipy.ndimage.filters as filters
import scipy.ndimage.morphology as morphology
import timeit
import math
# import cv2
from PIL import Image
%matplotlib inline
```

223
```
# Read grids from image
im = Image.open("cc_fin_new_hill.bmp")
Base = np.array(im)
```

224
```
# Define internal quantities and variables
scale = 0.25  # m per pixel
Nx = Base[:,0,0].size  # N appears to be resolution
Ny = Base[0,:,0].size  # Nx,Ny is size, Nz is RGB level
xmin=-scale*0.5*(Nx-1)
xmax=scale*0.5*(Nx-1)
ymin=-scale*0.5*(Ny-1)
ymax=scale*0.5*(Ny-1)
x = np.linspace(xmin, xmax, Nx) # This is defining the axes and full space
y = np.linspace(ymin, ymax, Ny)
Y, X= np.meshgrid(y, x)
TrailPotential = np.zeros((Nx,Ny))
DestinationPotential=np.zeros((Nx,Ny))
Weight=np.zeros((Nx,Ny))  # Create gradient to sit on Nx, Ny
intens=np.zeros((Nx,Ny))
q_alpha=np.zeros((Nx,Ny))
expdist=np.zeros((2*Nx-1,2*Ny-1))
dest=np.zeros((2))
start=np.zeros((2))
grad=np.zeros((2,Nx,Ny))
vel=np.asarray([0.,0.])
pos=np.asarray([0.,0.])
#desdirx=ReBiSpline(x,y,grad[0,:,:],s=2)
#desdiry=ReBiSpline(x,y,grad[1,:,:],s=2)
intens[:]=0.

#print(route)
#parameters
t_track=50. # Track decay time - after 50 walkers ignore a trail, it decays by 1/e
dt=0.1  # dt per time step, continuous markings every dt metres
dvel=1. # desired walker velocity in m/s
tau=5.
isigma=1./2. # trail potential
conv_thresh=10.e-4
precision=1.**2 #distance to target.
eps=0.025 #random motion contribution, same for all
p_alpha = 0.5 # value of persistence
prev_dir = 0 # record of previous angle of direction
theta_max = 0.05  # maximum permissible ascent gradient
```

225
```
class Slope:
    def __init__(self, posx, posy):
```

```
        xdir = gradx[posx][posy] # horizontal slope component at pos
        ydir = grady[posx][posy] # vertical slope component at pos
        self.xdir = xdir
        self.ydir = ydir
        self.mod = math.sqrt(xdir**2 + ydir**2)  # modulus of the gradient
        if self.xdir == 0: # 0 exceptions
            if self.ydir > 0:
                self.angle = math.pi/2
            elif self.ydir < 0:
                self.angle = -math.pi/2
        else:
            self.angle = math.atan(self.ydir/self.xdir)  # direction of the gradient vector

    def forbidden_angle(self, curDir):
        grad_max = math.tan(theta_max)
        if self.mod < grad_max:
            # Ignore gradient processing if maximum gradient is not exceeded anywhere
            return curDir
        else:
            thetaSlope = math.atan(self.mod)  # angle of the slope relative from ground to the heig
            thetaForbMin = self.angle - (math.pi/2 - math.asin(math.tan(theta_max)/math.tan(thetaSl
            thetaForbMax = self.angle + (math.pi/2 - math.asin(math.tan(theta_max)/math.tan(thetaSl
            if (curDir > thetaForbMin) and (curDir <= self.angle):  # current direction within left
                curDir = thetaForbMin
                return curDir
            elif (curDir < thetaForbMax) and (curDir > self.angle):  # current direction within rig
                curDir = thetaForbMax
                return curDir
            else:  # current direction outside of the forbidden zone
                pass # curDir remains unchanged
                return curDir
```

```
226 ##Set up map
#Create blank arrays for map
z = np.zeros((Nx,Ny))
g_max=np.zeros((Nx,Ny)) # empty matrix
g_nat=np.zeros((Nx,Ny))
g_grad=np.zeros((Nx,Ny))

g_nat=np.maximum(np.ones_like(g_nat),np.float64(Base[:,:,0])) # red channel, np.ones_like() sets mi
g_max=np.maximum(np.ones_like(g_max),np.float64(Base[:,:,1])) # green channel
g_height=np.maximum(np.ones_like(g_grad),np.float64(Base[:,:,2])) # blue channel
z=g_nat

# Trails (start and end point) For current Map, coordinates in metres, centre of image = (0,0)

# single possible path
route=np.array([[24.,-9.75],[-24.,9.75]]),

# commented out for single path

# route=np.array([[[-2.5,14.],[24.,-9.75]],
#                  [[-2.5,14.],[24.,2.5]],
#                  [[-2.5,14.],[-24.,9.75]],
#                  [[24.,-9.75],[-2.75,14.]],
#                  [[24.,-9.75],[-24.,9.75]],
#                  [[24.,2.5],[-2.75,14.]],
#                  [[24.,2.5],[-24.,9.75]],
#                  [[-24.,10.],[-2.75,14.]],
#                  [[-24.,10.],[24.,-9.75]],
#                  [[-24.,10.],[24.,2.5]]])
```

```
227 #Setup weight matrix, here trapezoid rule.
Weight[:,:]=1
```

```
Weight[1:-1,:]=2
Weight[:,1:-1]=2
Weight[1:-1,1:-1]=4
Weight*=0.25*((x[-1]-x[0])/(Nx-1))*((y[-1]-y[0])/(Ny-1))
#0.25*((x[-1]-x[0])/(N-1))*((y[-1]-y[0])/(N-1))
#np.exp(-np.sqrt((x[:,None]-x[N/2])**2+(y[None,:]-y[N/2])**2))*z[:,:]
```

228

```
# Setup distance matrix
for xi in range(1,Nx+1):
    for yi in range(1,Ny+1):

        expdist[xi-1,yi-1]=np.exp(-isigma*np.sqrt((x[Nx-xi]-xmin)**2+(y[Ny-yi]-ymin)**2))
        expdist[-xi,-yi]  = expdist[xi-1,yi-1]
        expdist[-xi,yi-1] = expdist[xi-1,yi-1]
        expdist[xi-1,-yi] = expdist[xi-1,yi-1]

# find index range > conv_thresh
subexpdist=expdist[(expdist>conv_thresh).any(1)]
subexpdist=subexpdist[:, np.any(subexpdist>conv_thresh, axis=0)]
#subexpdist=subexpdist[:,np.any(subexpdist>conv_thresh, axis=0)]
#expdist[subexpdist]=0.
subexpdist.shape
#expdist
#subexpdist
```

228

```
(111, 111)
```

229

```
def calc_tr_new():
    TrailPotential[:,:]=sg.convolve2d(z[:,:]*Weight[:,:],subexpdist[:,:],mode="same")  # 2D convolu
```

230

```
timeit.timeit(calc_tr_new,number=1)
```

230

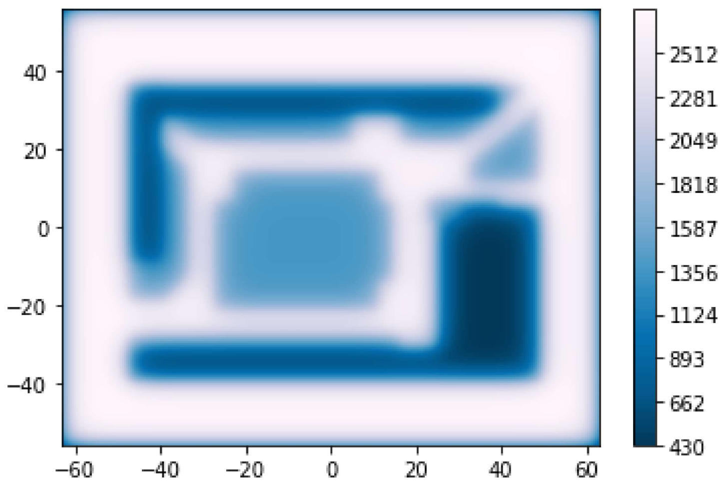
```
6.6357788000000255
```

231

```
# Defines a Plot to show the smoothing of the supplied map to represent the respective potentials o
# the potentials, the more attractive the ground is to the walker

cs = plt.contourf(X, Y, TrailPotential, levels=np.linspace(TrailPotential.min(),TrailPotential.max(
cbar = plt.colorbar()

#plt.scatter(track[0:1999,0],track[0:1999,1])
plt.show()
```



232

```
#set up walker
def set_up_walker(route_id):
```

```
    global vel,pos,track,intens,dest,start,route
    #start
    # start=np.array(route[route_id,0,:])  # commented for simplicity
    start = np.array([24.,-9.75])  # temporary one route
    dest = np.array([-24.,9.75])  # temporary one route
    #dest=(random.choice(ends))
    # dest=np.array(route[route_id,1,:]) # commented for simplicity
    vel=np.array([0.,0.])
    pos=np.array(start)
    #print (pos)
    track=np.zeros((2000,2))
    #track[0,:]=pos[:]
```

```
233 #Calculate gradients eq 19
#Trail gradient
def setup_potentials():
    global grad,desdirx,desdiry,dest
    grad=0.003*np.array(np.gradient(TrailPotential))
    #grad=0.002*np.array(np.gradient(TrailPotential)) ORIGINAL

    #print (dest)
    #Destination potential
    DestinationPotential=-np.sqrt((dest[0]-x[:,None])**2+(dest[1]-y[None,:])**2)
    #Combine gradients
    grad+=np.array(np.gradient(DestinationPotential)[:])
    #Normalise
    #grad[:,:,:]/=(np.sqrt(grad[0,:,:]**2+grad[1,:,:]**2))
    desdirx=ReBiSpline(x,y,grad[0,:,:],s=2) # gradeint plus magnitude, Spline approximation over a
    desdiry=ReBiSpline(x,y,grad[1,:,:],s=2)
    # angle array, arctans of gradient components, rebislpine
    # continuous desired angles permissible
        # 2pi periodic system aware
```

```
234 # #Plot the direction
# scgrad=np.arctan2(grad[1],grad[0])
# levels = np.linspace(-np.pi, np.pi, 360)
# cs = plt.contourf(X, Y,scgrad, levels=levels,cmap='hsv')

# cbar = plt.colorbar()
# # ERROR # plt.scatter(track[0:1999,0],track[0:1999,1])
# #plt.scatter(start, dest)
# print(start)
# print(dest)
# plt.show()
```

```
235 # Apply inclination rule to change to direction of the walker
def check_direction(cur_dir):
    global x, y, prev_dir
    # Apply persistence of direction formula (Gilks equation 6)
    gamma = (p_alpha * prev_dir) + (1 - p_alpha)*cur_dir
    # self.forbidden_angle()
    return x, y
```

```
236 def calc_path():
    global pos,vel,intens,track,dest,dvel,tau, prev_dir, desdirx, desdiry
    i=0
    hist=10
    samp=10
    avpos=np.zeros((2,hist))
    #Setup While loop to run until either the walker reaches the destination or the walker has pass
    #attempt to get there
    while (np.dot(pos-dest,pos-dest)>precision and i<2000):
        #set the postiion of the walker on its first then subsequent cycles
```

```
        #conditional logic saying to update the average position of the walker every 10 iterations
        #if (i%samp==0): avpos[:,(i%hist)//samp]=pos[:] #ORIGINAL
        if (i%samp==0):
            avpos[:,(i%(hist*samp))//samp]=pos[:]
        #print((i%hist)//samp)
        # print(avpos)
        gradmagnitude=max(0.0001,np.sqrt(desdirx(pos[0],pos[1])**2+desdiry(pos[0],pos[1])**2))
        xi=np.array(np.random.normal(0,1,2))
        # Equation 6 in Helbing, differential in position, eliminised velocity decay components
        # gradmagnitude makes sure it is normalised, desdir not normalised
        pos[0]+= dt *(dvel * desdirx(pos[0],pos[1])/gradmagnitude +np.sqrt(2.*eps/tau)*xi[0])  # x-
        pos[1]+= dt *(dvel * desdiry(pos[0],pos[1])/gradmagnitude +np.sqrt(2.*eps/tau)*xi[1])  # y-
#       posGrad = math.degree(math.atan(pos[0]/pos[1]) # future position
        curDir = math.atan(desdiry(pos[0],pos[1])/desdirx(pos[0],pos[1]))
        prevDir = curDir # applying a back trace of the previous direction# Calculate current facin
        curGradient = Slope(round(pos[0]),round(pos[1]))  # set the current gradient to the Slope c
        curDir = curGradient.forbidden_angle(curDir) # apply forbidden angle rule
        if prevDir != curDir:  # the position angle has changed, recalculate the path position ???
            desdiry = math.sin(curDir)
            desdirx = math.cos(curDir)
            gradmagnitude=max(0.0001,np.sqrt(desdirx(pos[0],pos[1])**2+desdiry(pos[0],pos[1])**2))
            xi=np.array(np.random.normal(0,1,2))
            pos[0]+= dt *(dvel * desdirx(pos[0],pos[1])/gradmagnitude +np.sqrt(2.*eps/tau)*xi[0])
            pos[1]+= dt *(dvel * desdiry(pos[0],pos[1])/gradmagnitude +np.sqrt(2.*eps/tau)*xi[1])
        # pos+=dt*vel
        #vel[0]+=-1/tau*vel[0] + (dvel/tau)*desdirx(pos[0],pos[1])/gradmagnitude+np.sqrt(2.*eps/tau
        #vel[1]+=-1/tau*vel[1] + (dvel/tau)*desdiry(pos[0],pos[1])/gradmagnitude+np.sqrt(2.*eps/tau

        #Set the current position of the walker into the trakc array for the current iteration
        track[i,:]=pos[:]
        intens[int((pos[0]-xmin)*(Nx-1)/(xmax-xmin)),int((pos[1]-ymin)*(Ny-1)/(ymax-ymin))]+=1.
        i+=1
        if (i%(hist*samp)==0):
            meanpos=np.mean(avpos,axis=1)
            if (np.dot(pos-meanpos,pos-meanpos)<precision):
                print ("Stalled progress ",pos,meanpos,vel, dest)
                break
    if (i==2000): print ("Missed goal ",dest,pos)
    return i
#stopping condition
```

237

```
# Calculate Q_alpha (strength of markings) eq 15
def update_ground():
    global q_alpha,intens,z,g_max,t_track,g_nat
    q_alpha=intens*(1.-z/g_max)
    # Time evolution of ground potential
    #zdiff=(1./t_track)*(g_nat-z)+q_alpha
    z+=(1./t_track)*(g_nat-z)+q_alpha
    #cs = plt.contourf(X, Y, zdiff, cmap=cm.PuBu_r)
    #cbar = plt.colorbar()
    #plt.show
    #z[140:160,45:75]
```

238

```
def plot_path():
    plt.contourf(X, Y, z, levels=np.linspace(z.min(),z.max(),1000),cmap='PuBu_r')
    plt.colorbar()
    #plt.scatter(track[0:1999,0],track[0:1999,1],1)
    plt.show(block=False)
```

239

```
tau = 5.
```

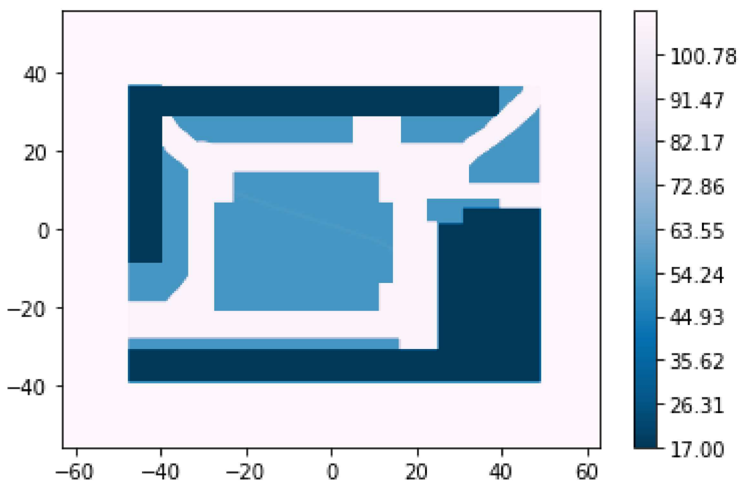
240

```
g_slope = np.gradient(g_height,1)
grady = g_slope[0] # vertical slope compontent
```

```
gradx = g_slope[1] # horizontal slope component
for i in range(0,1):
    calc_tr_new()
    intens[:]=0.
    for j in range(0,1):
        set_up_walker(np.random.randint(0,len(route)))
        setup_potentials()
        #calc_path()
        print(i, start," -> ", dest, pos, calc_path())
    update_ground()
    #plot_path()
```

```
0 [24.   -9.75]  ->  [-24.     9.75] [-23.1127701    9.57253925] 514
```

241
```
plot_path()
```



242
```
for i in range(0,Nx):
    for j in range(0,Ny):
        if (np.isnan(z[i,j])):
            print (i,j,g_max[i,j],Base[i,j,0])
```

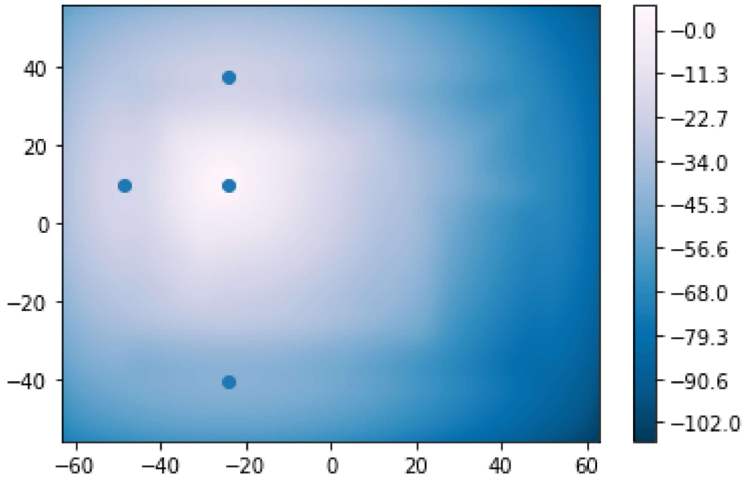
243
```
def detect_local_maxima(arr):
    # https://stackoverflow.com/questions/3684484/peak-detection-in-a-2d-array/3689710#3689710
    """
    Takes an array and detects the troughs using the local maximum filter.
    Returns a boolean mask of the troughs (i.e. 1 when
    the pixel's value is the neighborhood maximum, 0 otherwise)
    """
    # define an connected neighborhood
    # http://www.scipy.org/doc/api_docs/SciPy.ndimage.morphology.html#generate_binary_structure
    neighborhood = morphology.generate_binary_structure(len(arr.shape),2)
    # apply the local minimum filter; all locations of minimum value
    # in their neighborhood are set to 1
    # http://www.scipy.org/doc/api_docs/SciPy.ndimage.filters.html#minimum_filter
    local_max = (filters.maximum_filter(arr, footprint=neighborhood)==arr)
    # local_min is a mask that contains the peaks we are
    # looking for, but also the background.
    # In order to isolate the peaks we must remove the background from the mask.
    #
    # we create the mask of the background
    background = (arr==0)
    #
    # a little technicality: we must erode the background in order to
    # successfully subtract it from local_min, otherwise a line will
    # appear along the background border (artifact of the local minimum filter)
    # http://www.scipy.org/doc/api_docs/SciPy.ndimage.morphology.html#binary_erosion
    eroded_background = morphology.binary_erosion(
        background, structure=neighborhood, border_value=1)
    #
```

```
    # we obtain the final mask, containing only peaks,
    # by removing the background from the local_min mask
    detected_maxima = local_max ^ eroded_background
    return np.where(detected_maxima)
```

244
```
def plot_potentials():
    global dest
    TotPot = np.zeros((Nx,Ny))
    TotPot =- np.sqrt((dest[0]-x[:,None])**2+(dest[1]-y[None,:])**2)
    TotPot += 0.003*TrailPotential
    maxima=detect_local_maxima(TotPot)
    cs = plt.contourf(X, Y, TotPot, levels=np.linspace(TotPot.min(),TotPot.max(),1000),cmap='PuBu_r
    cbar = plt.colorbar()
    print(maxima)
    plt.scatter(x[maxima[0]],y[maxima[1]])
    plt.show()
    # commit test
```

245
```
plot_potentials()
```

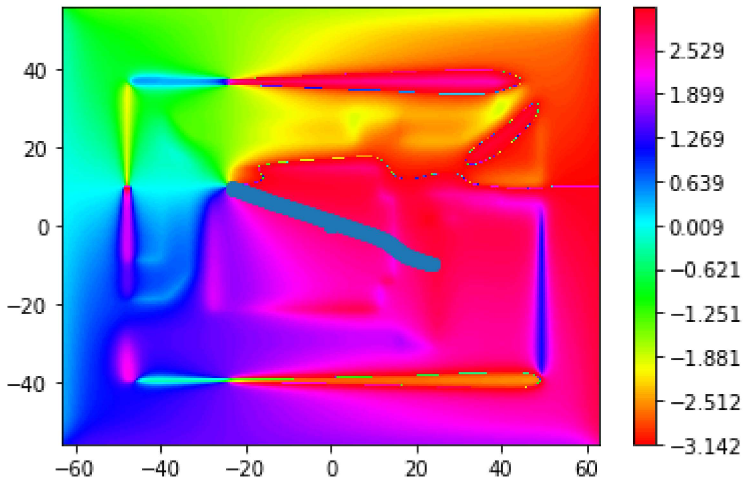
```
(array([ 58, 156, 156, 156], dtype=int64), array([262,  62, 262, 373], dtype=int64))
```



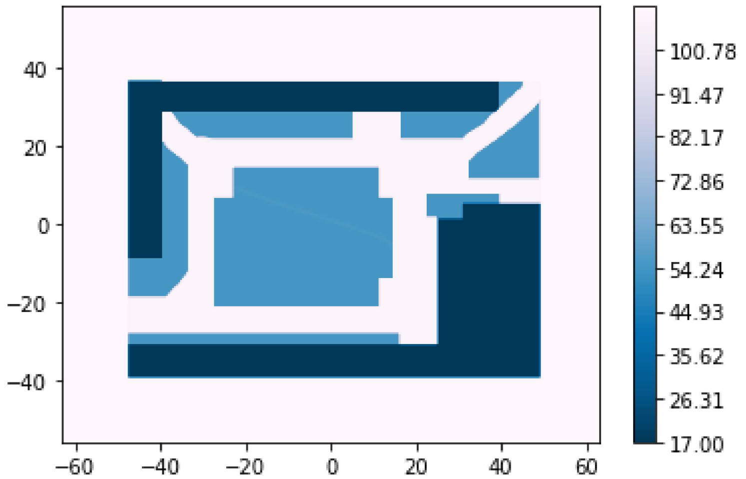
246
```
#Plot the direction
scgrad=np.arctan2(grad[1],grad[0])
levels = np.linspace(-np.pi, np.pi, 360)
cs = plt.contourf(X, Y,scgrad, levels=levels,cmap='hsv')

cbar = plt.colorbar()
plt.scatter(track[0:1999,0],track[0:1999,1])
#plt.scatter(start, dest)
print(start)
print(dest)
plt.show()
```

```
[24.   -9.75]
[-24.     9.75]
```



247 plot_path()



248
```
#Integrate z, trapezoid rule eq 20
# def calc_tr():
#    global xi,yi,TrailPotential,expdist,z,Weight,Nx,Ny
#    for xi in range(0,Nx):
#        for yi in range(0,Ny):
#            TrailPotential[xi,yi]=np.sum(expdist[Nx-1-xi:2*Nx-1-xi,Ny-1-yi:2*Ny-1-yi]*z[:,:]*Weigh
```